INSTRUMENT AUTONOMY TECHNIQUES ENHANCE SCIENCE RETURN AND EFFICIENCY OF SURFACE MISSIONS. R. Francis[1], T. A. Estlin[1], K. Wagstaff[1], G. Doran[1] and L. Mandrake[1] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California (raymond.francis@jpl.nasa.gov)

Introduction: Robotic exploration missions, operating spacecraft at great distances from Earth, face challenges in data throughput and latency, with consequences for mission scope, productivity, and science return. This abstract describes advances achieved for surface missions; autonomous science for orbital and flyby missions is described in [1].

Surface missions, which often study very localized, fine-scale, and diverse features, face further obstacles due to short mission durations and restricted communications geometry. Many of these can be addressed by including capabilities for instrument autonomy and onboard intelligence with respect to acquiring or prioritizing measurements. A number of such techniques have already aided planetary missions, and new capabilities are under development. Given the significant increase in science return and the new observations that can be enabled, capabilities for instrument autonomy should be an important part of the design and selection of instrument systems for planetary missions.

Autonomy as a scalable class of tools: Instruments equipped with a degree of autonomy can be more powerful tools for the science team on Earth than those without – just as an autofocus capability increases the ease and reliability of operating a camera. The degree of autonomous operation can vary greatly, and should be selected based on the particular science goals, instrument capabilities, and working environment to best enhance the outcome the observations. A number of specific examples are given below.

Data triage: Data budgets for planetary missions are always very constrained. An onboard system capable of recognizing high-value observations and prioritizing them for downlink increases the average value of transmitted data, and the overall value of the mission's data set. The WATCH software system aboard the MER Opportunity rover analyzes images for the presence of clouds and dust devils – both rare features of interest to the science team – and prioritizes images containing them for transmission to Earth [2]. WATCH demonstrated a 70% reduction in data volume for dust devil monitoring campaigns [3].

Novelty detection: Techniques exist to automatically recognize data, which are out of family with past observations. Whether in images, spectra, or other data, onboard recognition of novel features can be used in a number of ways – as part of the data triage process, or to command additional observations with the same or another instrument. The DEMUD algorithm [4] has been applied to LIBS data from the Curiosity rover's ChemCam instrument, for example, to automatically recognize unusual geochemical spectra [5], and autonomous onboard use of such a system would provide many of the benefits discussed above.

Pointing refinement: There are numerous technical and operational challenges to precise pointing of narrow-field instruments. ChemCam is often used to target small-scale features such as veins in rocks, which may be as small as a few millimeters in width. The AEGIS software system aboard the Curiosity rover allows autonomous real-time pointing refinement for observing such features [6]. The science team on the ground selects a desired target (such as bright-toned veins in an outcrop) and commands ChemCam to observe it with the Remote Micro-Imager (RMI) context camera. AEGIS identifies the desired features, in the image, and, retargets ChemCam to correct any offset. In this way, a few minutes of imaging and automated analysis can save a day or more of delay of making a second targeting attempt. The capability has been demonstrated on Mars and is available whenever the science team finds suitable targets.

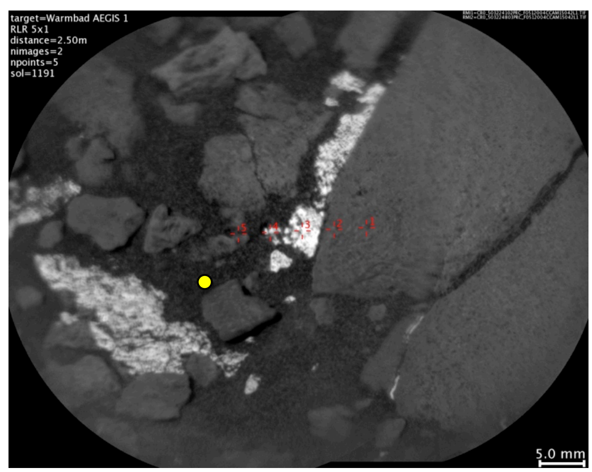

Fig 1, AEGIS pointing refinement: ChemCam RMI mosaic, showing LIBS spots measured on sol 1191. ChemCam initial pointing shown in yellow.

A new capability under development for narrow-field instruments on the Mars 2020 rover allows operators to specify a particular target of interest in an instrument's view on one sol, then return precisely to this location on a subsequent sol using a visual alignment of the instrument's view across the two sols to account for any drift that might have occurred in the intervening period due to thermal fluctuations or rover settling [7]. This capability will be essential for arm-mounted instruments like PIXL, for which the region targeted for science measurements is on the order of the error in arm placement from sol-to-sol (~1 cm).

Autonomous targeting: AEGIS is also capable of selecting targets on its own, following criteria set by the science team [8]. AEGIS analyzes images from the Curiosity rover's navigation cameras (NavCams) and identifies distinct geological features by a combination of computer vision techniques. It then filters and ranks these objects, choosing one or more which best match the science team's request(s). ChemCam measurements of these targets are then automatically made.

Such a capability is very useful, for example, after driving into new terrain not yet seen by the team on Earth; rather than waiting for post-drive images to be downlinked at the next opportunity, and for the science team to inspect them, select targets, and uplink commands, AEGIS can quickly deliver geochemical spectra from the post-drive location. The science team employs a mix of ground-targeted observations (when possible) and AEGIS automated targeting (when appropriate), with the latter occurring after most drives since the system became available.

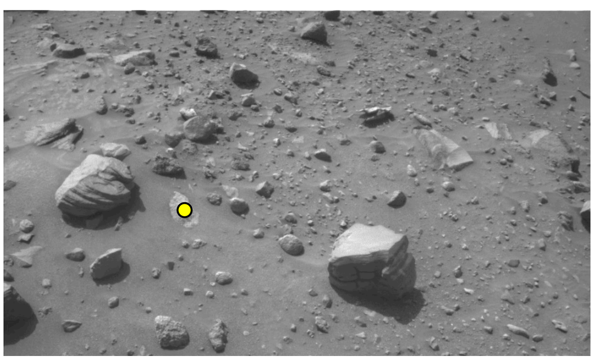

Fig 2, Autonomous targeting: NavCam scene analyzed by AEGIS on MSL sol 1400, set to find bright patches of outcrop. The top-ranked target (yellow marker) was automatically measured with ChemCam.

An upgrade in development would augment AEGIS targeting with automated pixelwise classification of geological materials using the TextureCam system [9], which demonstrated full-image classification onboard its instrument in under 1 second.

Autonomous rescheduling: An instrument that can detect notable events and measurements can also be set to trigger changes in the spacecraft's schedule of activities. This can be used to acquire more data of a recognized novel or high-priority feature or event, or to defer a routine or low-priority activity in response to a high-priority observation opportunity. For example, the Earth-observing EO-1 satellite is able to autonomously recognize active volcanoes in hyperspectral data, acquire opportunistic data on those targets quickly, and reschedule the originally-planned observations for later opportunities [10]. Similar replanning could be used for a rover to recognize particular types of geological material, or an airborne system (on Titan or Venus) to respond to certain types of terrain or other conditions.

Where autonomy contributes: Instrument autonomy, at any level, is most useful when circumstances reduce the ability of the science team to be in the loop for operations. Long periods without communication, or long light-time delays, make it difficult to share information between the Earth and a distant planet. Transient events require either autonomous detection or routine monitoring with autonomous data triage to reduce data volumes. For mobile platforms (roving or airborne), important or novel features may pass entirely by before Earth sees them; autonomous detection, response, and data acquisition can allow discovery and study of things that would have been missed entirely.

Even now, AEGIS on MSL contributes 'opportunistic science', by making valuable measurements on as-yet-unseen-by-Earth materials during post-drive periods which would otherwise be idle or underused time on Mars. Similar underused periods occur on many missions. When data throughput is limited, the mission science return is enhanced by systems, which can intelligently select the most desirable, most representative, or most unusual data to send to Earth.

Conclusion: Existing, flight-proven, and near-future autonomy capabilities can enhance the value of science instruments, and consequently of planetary missions, by increasing the quality and throughput of data, and by making more efficient use of precious planetary surface time. Instrument and mission design benefits from considering and promoting these capabilities – at the concept definition, proposal, development, and operation phases.

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